Spatial distribution of isoprene emissions from North America derived from OMI formaldehyde column measurements

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with

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thanks to

NASA-ACMAP

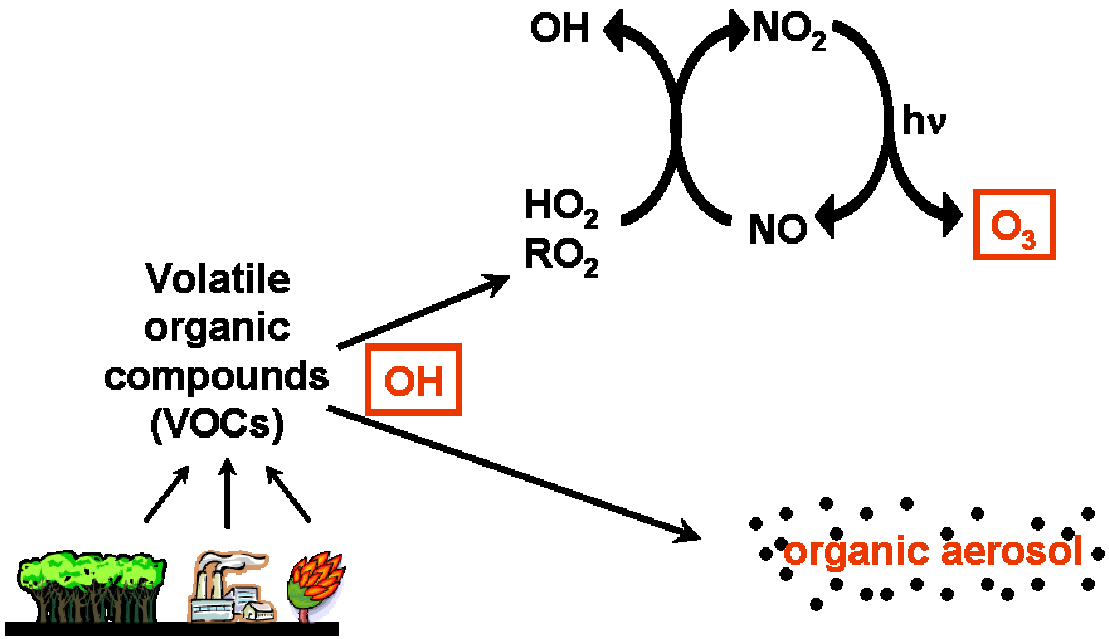
NOAA C&GC Postdoctoral Program

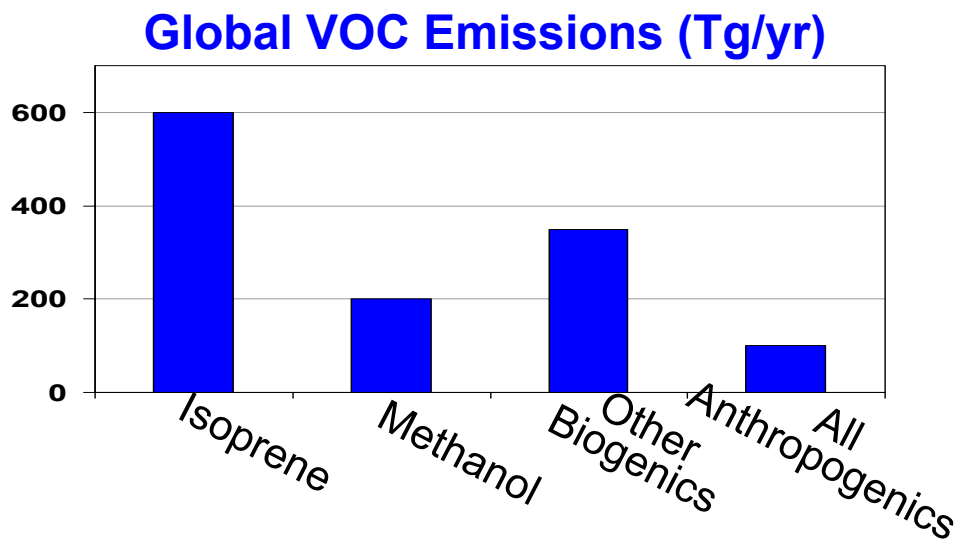
OMI Science Team

INTEX Science Teams

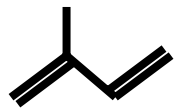
Aura Science Team Meeting
October 5, 2007

Isoprene: The Most Important Non-Methane VOC





Isoprene

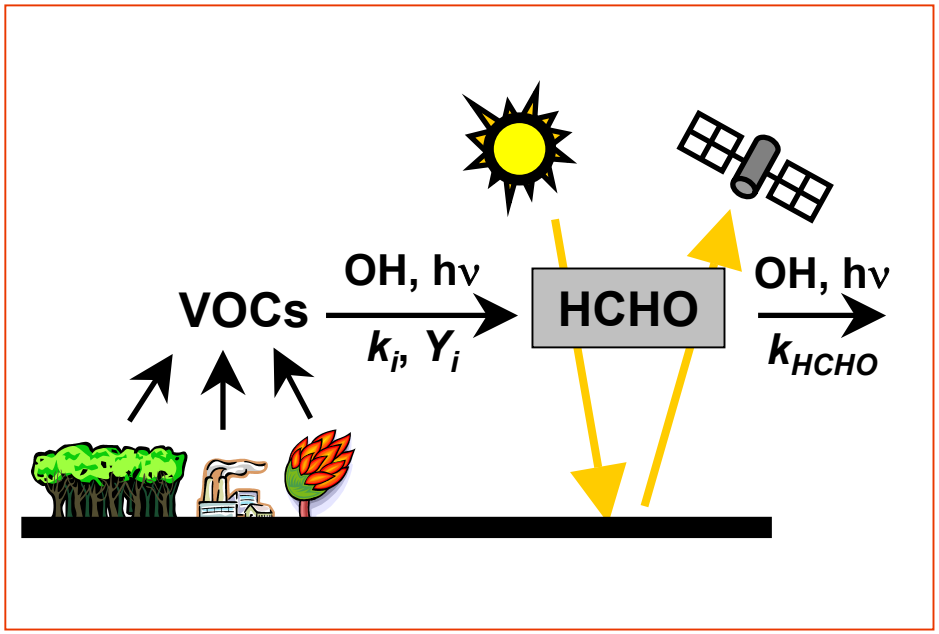


Global emissions ~ methane
(but > 10^4 times more reactive)

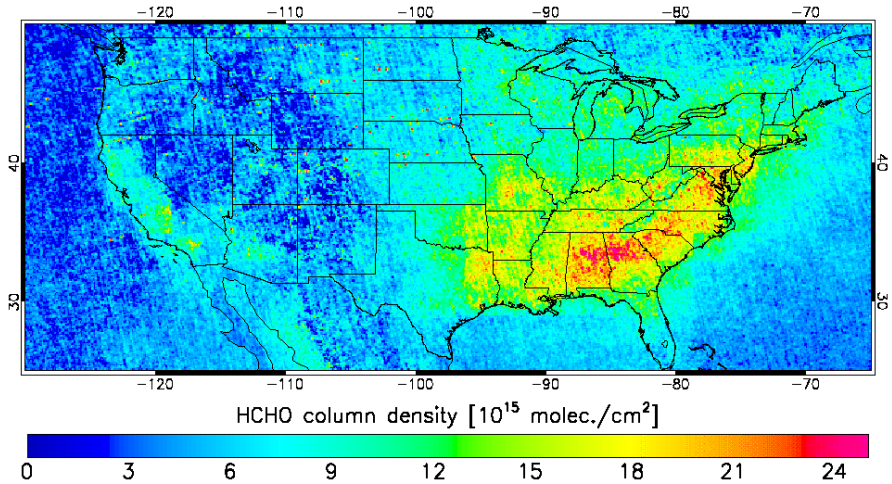
~ 6x anthropogenic VOC emissions

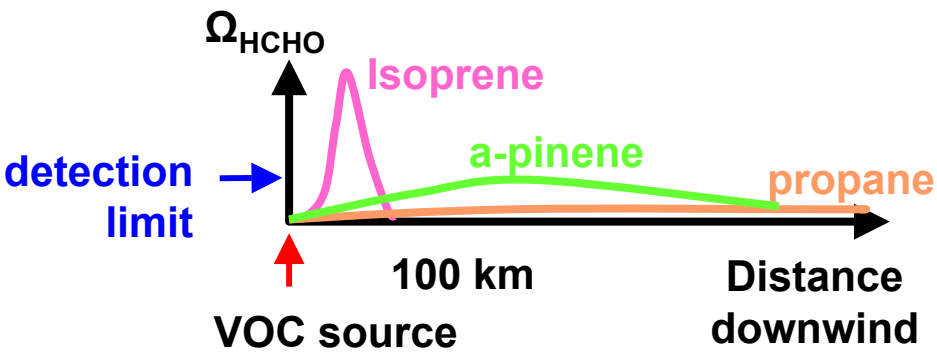
Produced enzymatically in plant chloroplasts

Relating HCHO Columns to Isoprene Emission



HCHO vertical columns measured by OMI
(Summer 2006)





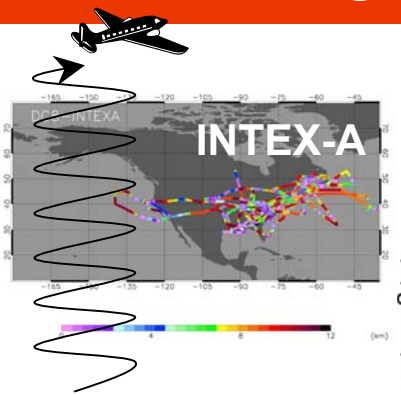
Palmer et al., JGR (2003,2006)
Millet et al., JGR (2006)

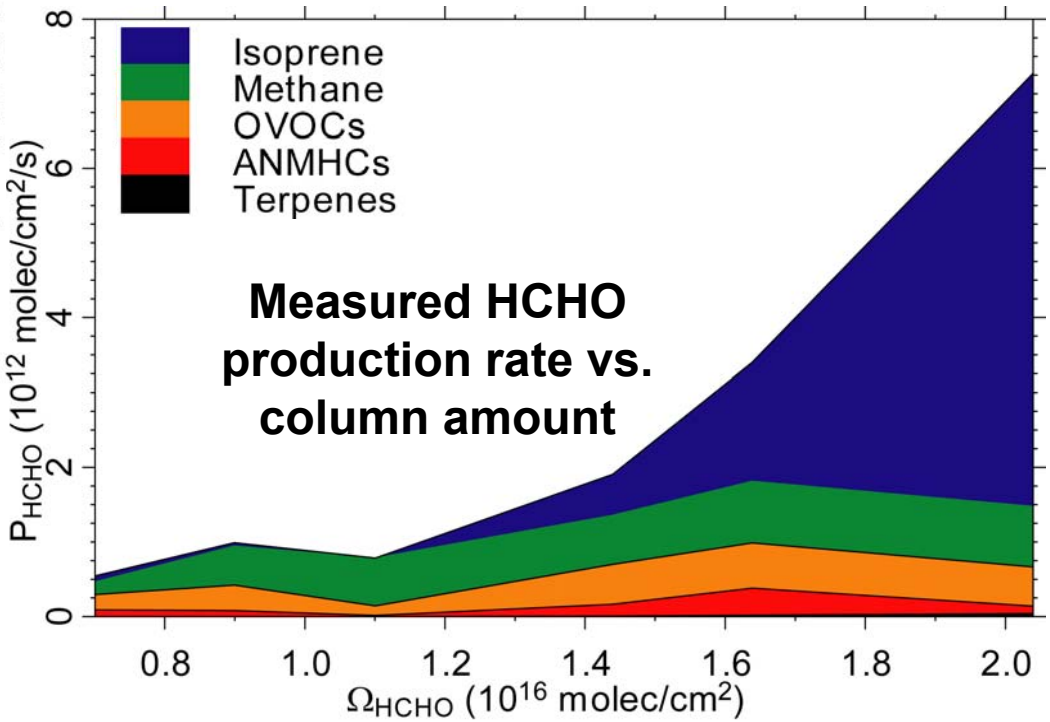
Local Ω_{HCHO}-E_i Relationship

$$\Omega_{HCHO} = \frac{1}{k_{HCHO}} \sum_i Y_i E_i$$

$$\Omega_{HCHO} = S \cdot E_{isoprene} + B$$

Relating HCHO Columns to Isoprene Emission





What drives variability in column HCHO?

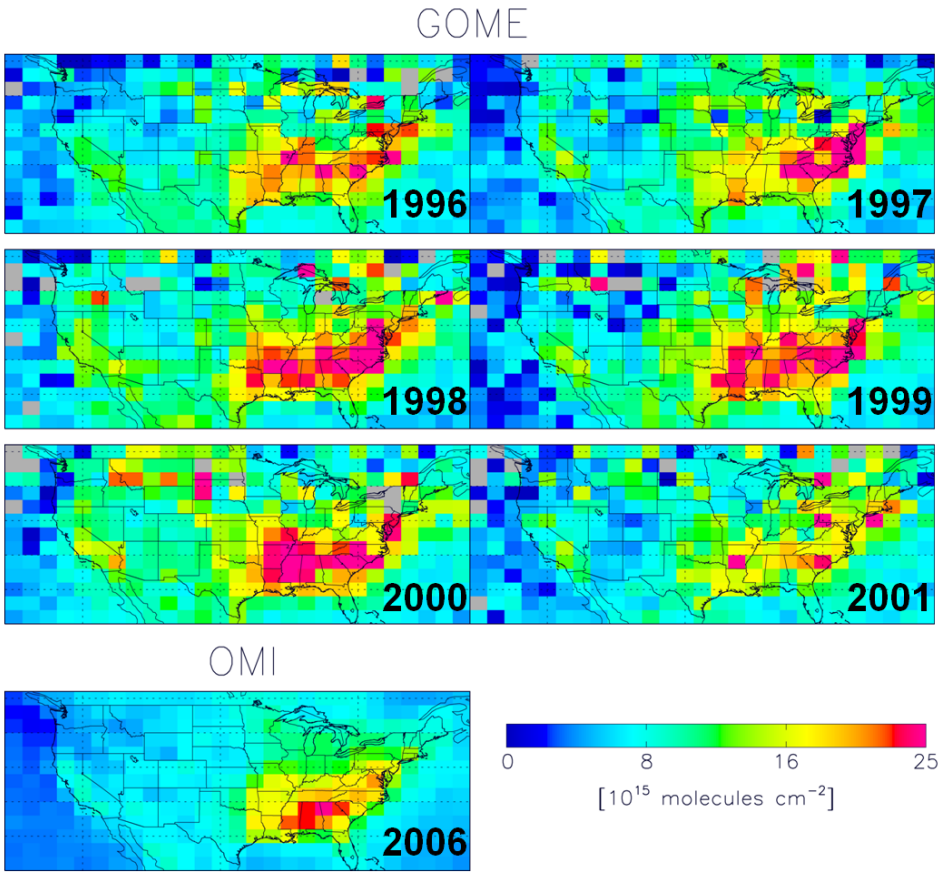
Isoprene dominant source when Ω_{HCHO} is high

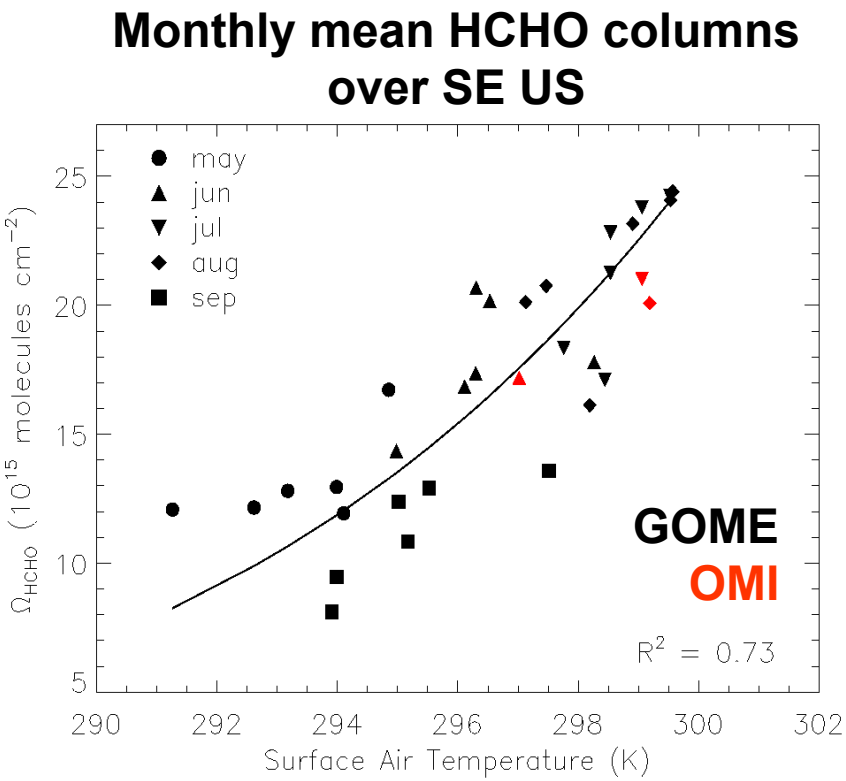
Other VOCs give rise to a relatively stable background Ω_{HCHO}
→ Not to variability detectable from space

Ω_{HCHO} variability over N. America driven by isoprene

Millet et al., JGR (2006).

OMI vs. GOME

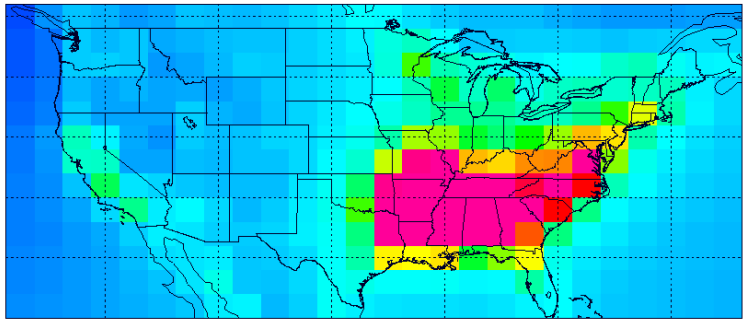




Updated OMI HCHO within 2-14% of GOME over US
(after accounting for interannual climate differences)

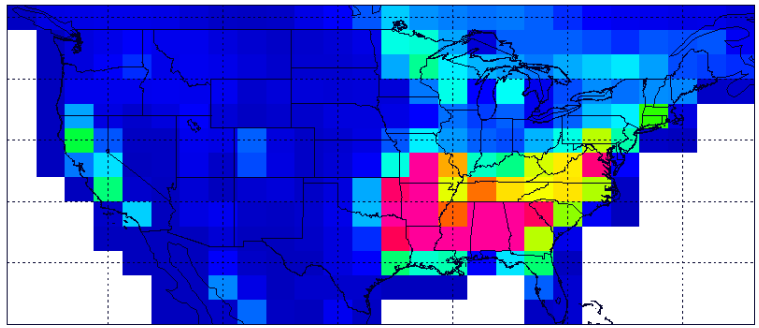
Relating HCHO Columns to Isoprene Emissions

GEOS–Chem HCHO Column

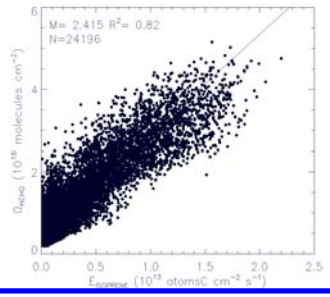


[10^{15} molecules cm^{-2}]

MEGAN_V2 Isoprene Emission



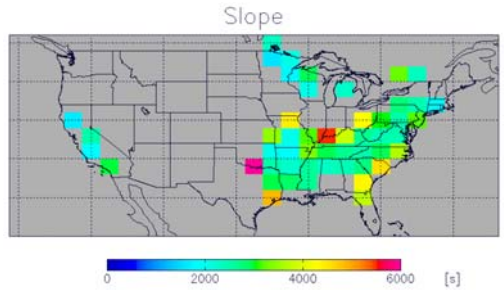
[10^{13} atomsC cm^{-2} s^{-1}]



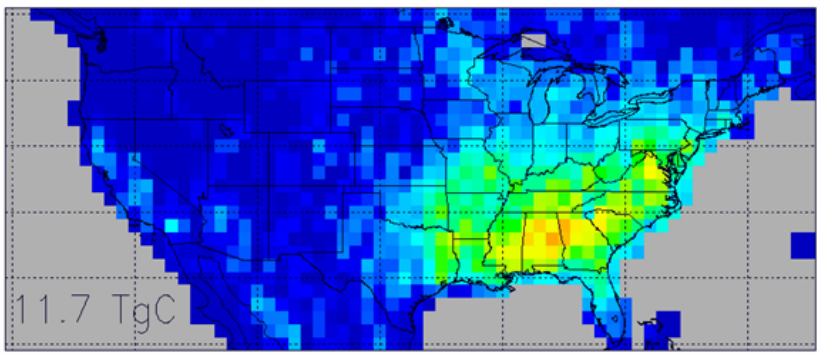
$$\Omega_{HCHO} = SE_{isoprene} + B$$

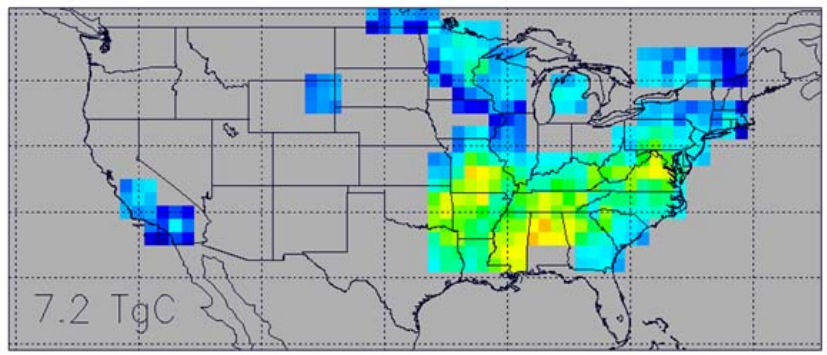
Uniform Ω_{HCHO}-$E_{isoprene}$ relationship

Variable Ω_{HCHO}-$E_{isoprene}$ relationship



OMI Isoprene Emission



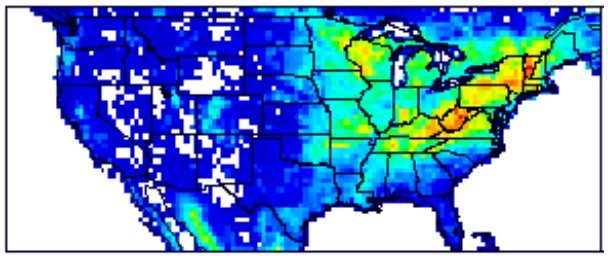


[10^{13} atomsC cm^{-2} s^{-1}]

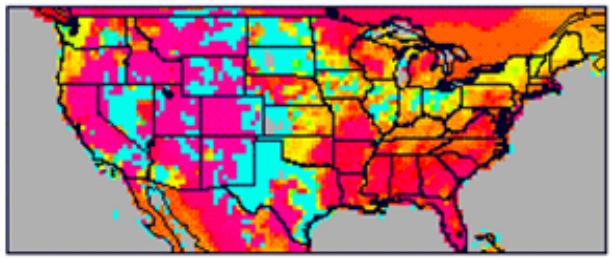
Model of Emissions of Gases and Aerosols from Nature

Guenther et al., ACP (2006)

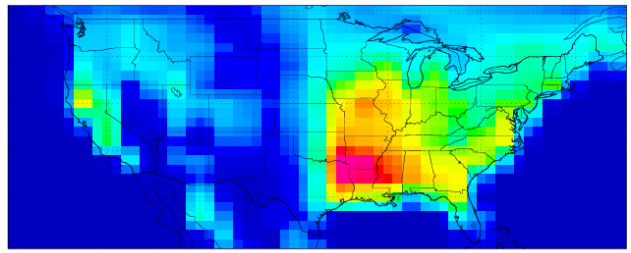
Land cover database
(Community Land Model, AVHRR)



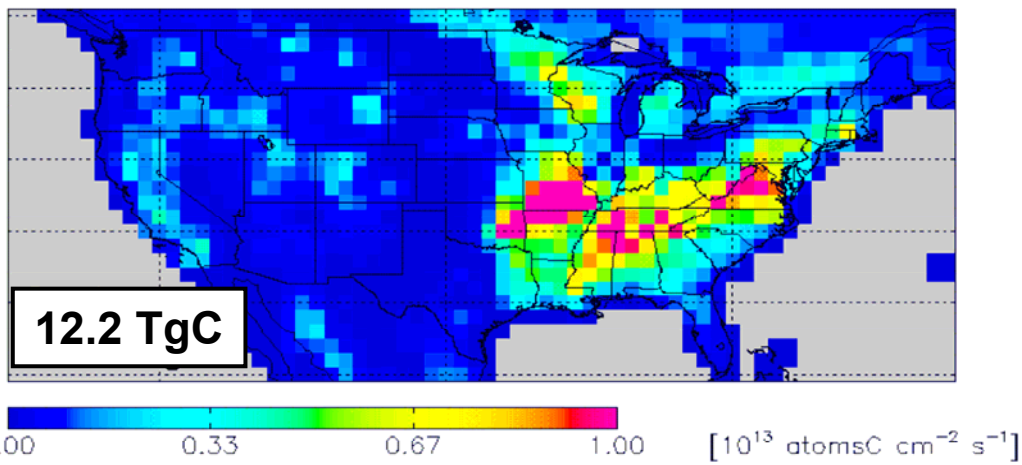
Vegetation-specific baseline emission factors



Environmental drivers
(T, hν, LAI, leaf age, …)



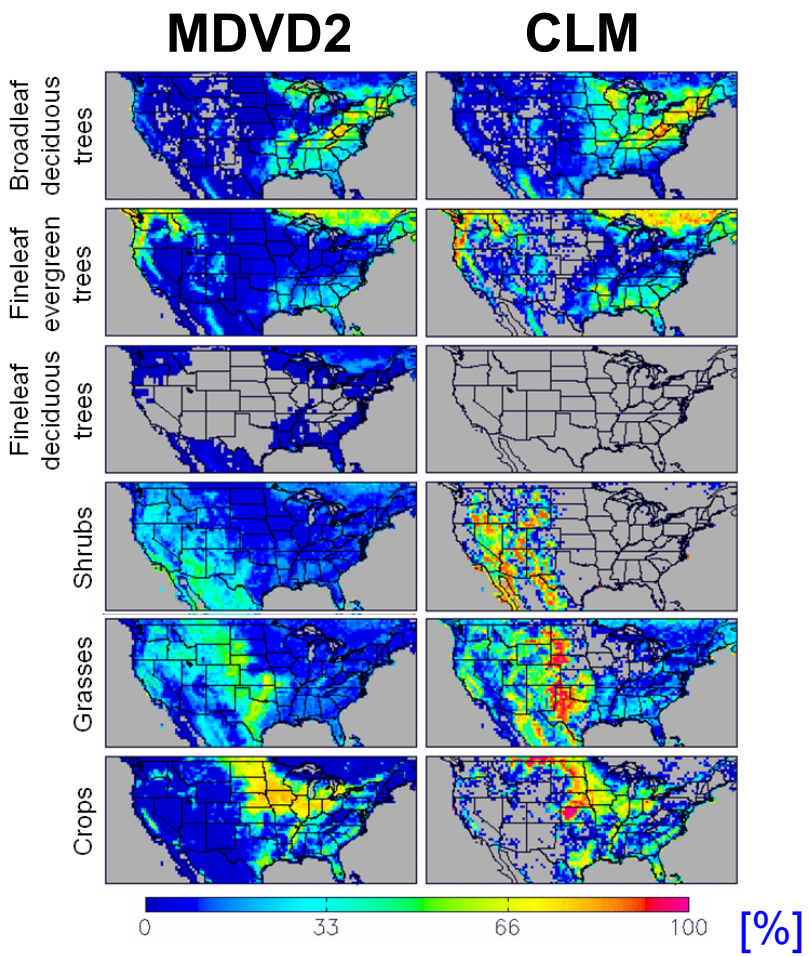
MEGAN Isoprene Emissions (June-August, 2006)



Drive MEGAN with 2 Land Cover Databases

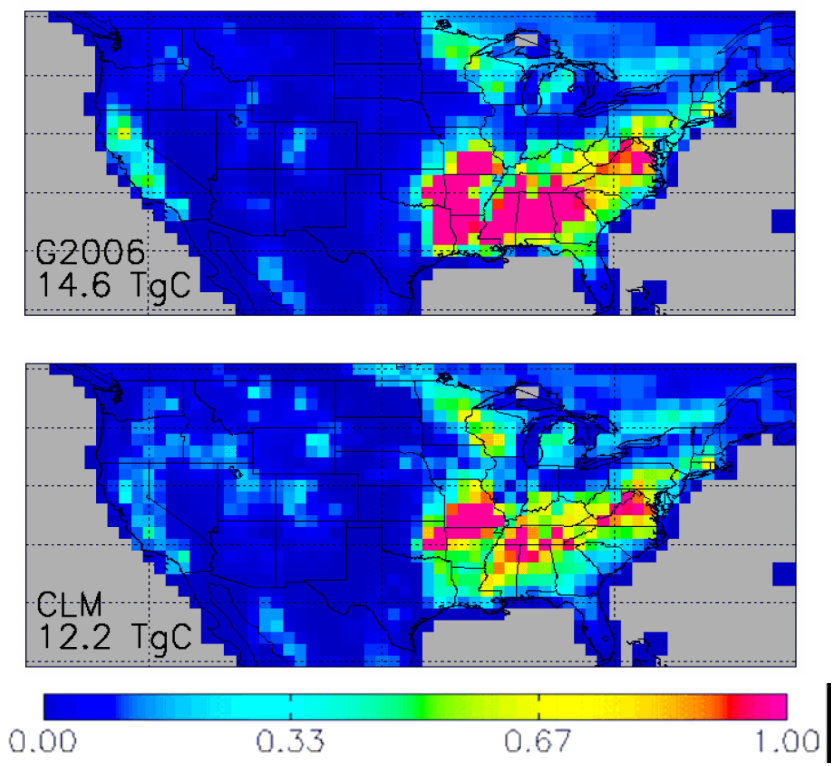
MDVD2 (MODIS/AVHRR/Ground truth)
CLM (AVHRR/IGBP DISCover)

Plant Functional Type Coverage



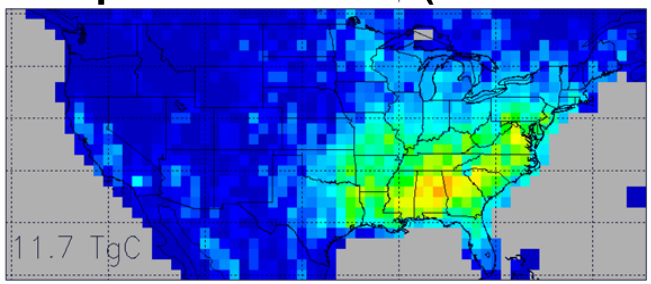
Isoprene Emission

June-August 2006

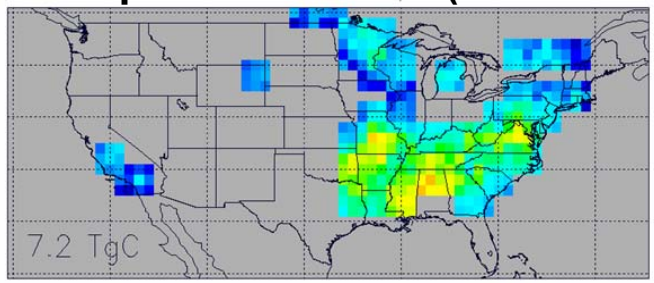


OMI Isoprene Emission vs. MEGAN-CLM

OMI isoprene emission (uniform slope)



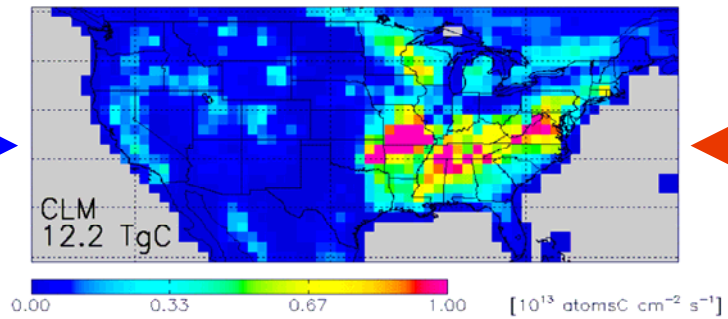
OMI isoprene emission (variable slope)



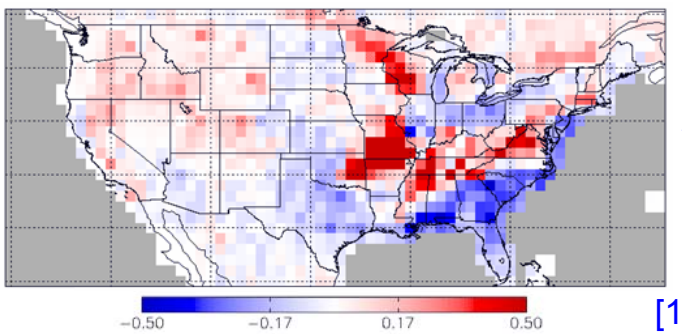
Uniform Ω_{HCHO}-$E_{isoprene}$ relationship

Variable Ω_{HCHO}-$E_{isoprene}$ relationship

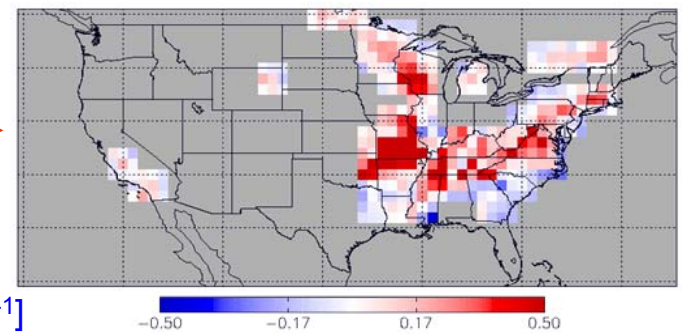
MEGAN w/ CLM vegetation



MEGAN - OMI



MEGAN - OMI



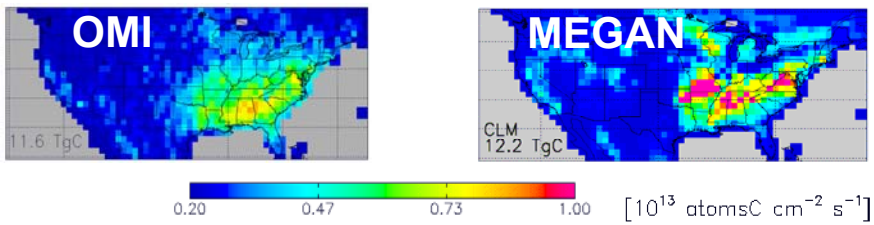
[10^{13} atomsC cm^{-2} s^{-1}]

Spatial Patterns in Isoprene Emissions

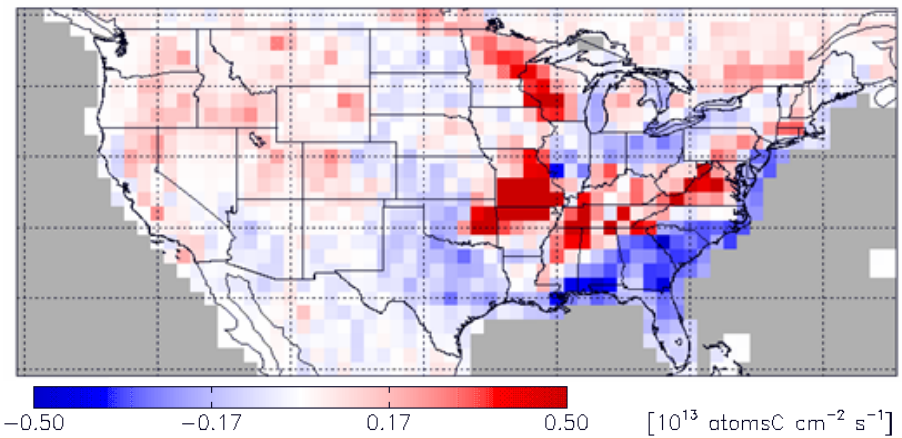
MEGAN higher than OMI over dominant emission regions

Large sensitivity to surface database used

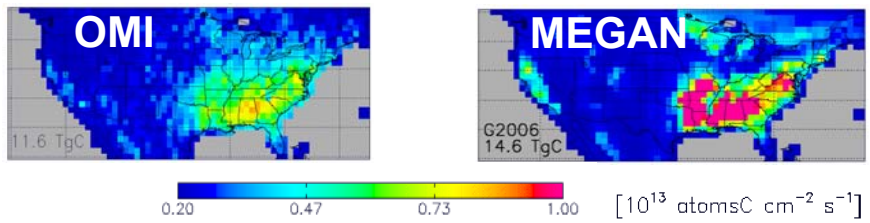
MEGAN with CLM vegetation



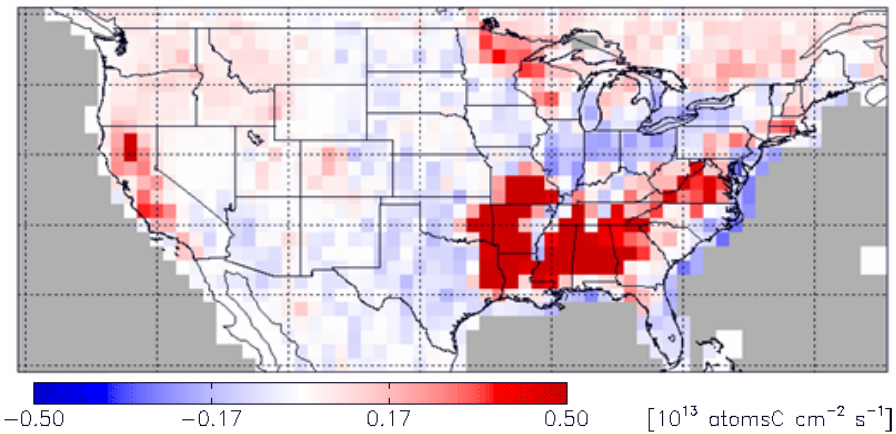
MEGAN - OMI Isoprene Emissions
June-August, 2006



MEGAN with MDVD2 vegetation



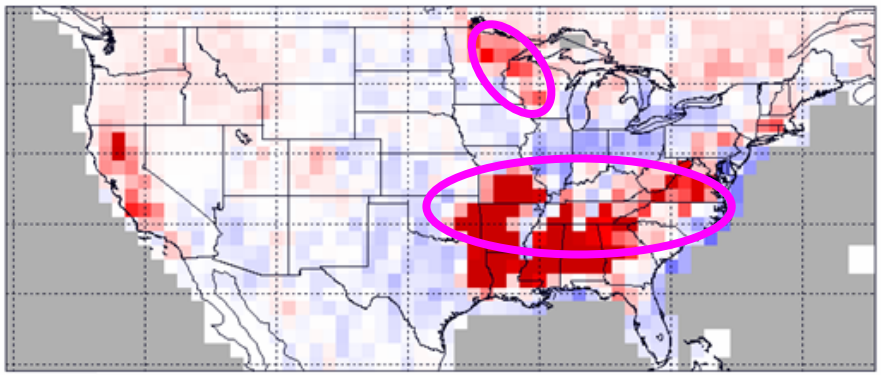
MEGAN - OMI Isoprene Emissions
June-August, 2006



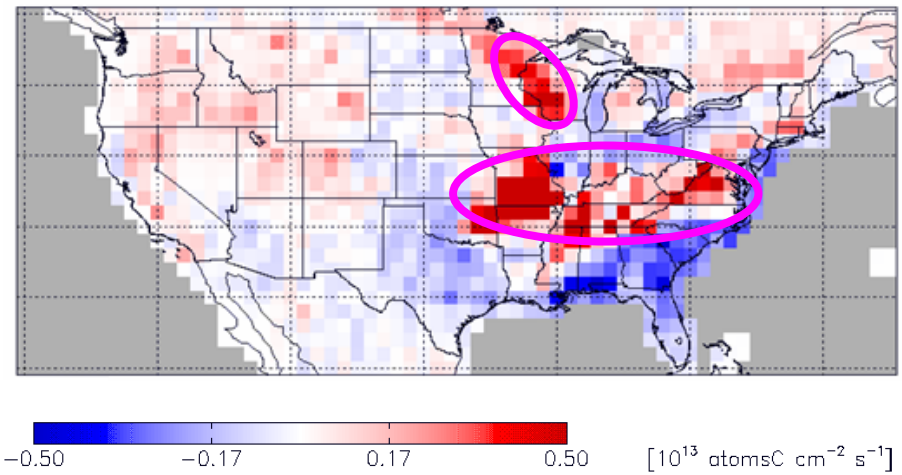
Bottom-Up Emissions Too High in Dominant Source Regions

MEGAN - OMI Isoprene Emissions
June-August, 2006

MEGAN w/ MDVD2 Land Cover



MEGAN w/ CLM Land Cover

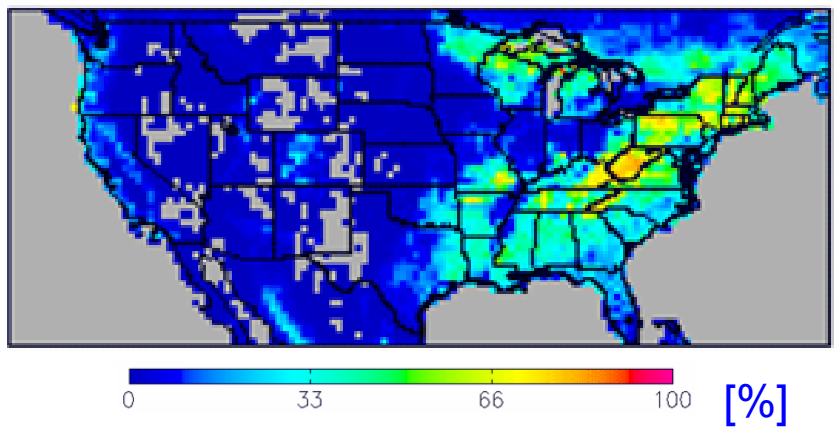


MEGAN emissions >70% too high over much of the Ozark Plateau, Upper South, Upper Midwest

Large regional emissions driven by oak tree cover, high temperatures

Broadleaf tree isoprene emissions overestimated

MDVD2 Broadleaf Trees

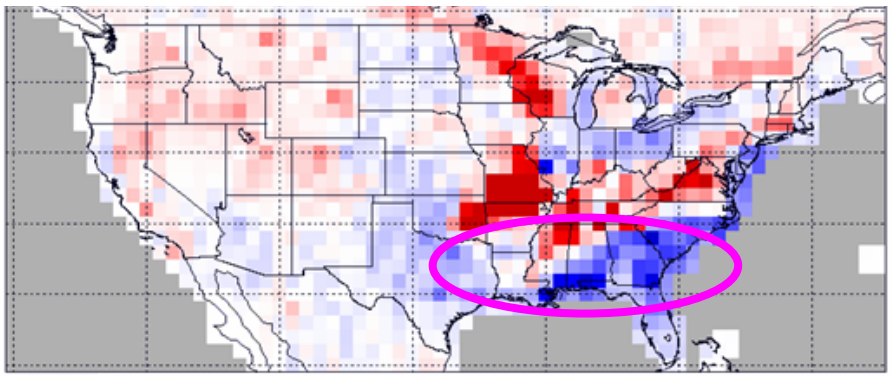


CLM-Driven Emissions Too Low in Deep South

Bias in modeled emissions: >100%

OMI – MEGAN Isoprene Emissions

June-August, 2006



[10^{13} atomsC cm^{-2} s^{-1}]

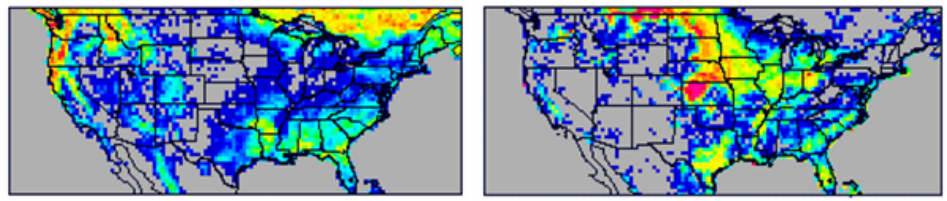
Underestimate of broadleaf tree coverage in understory

-or-

Modeled emissions from evergreen trees or crops too low

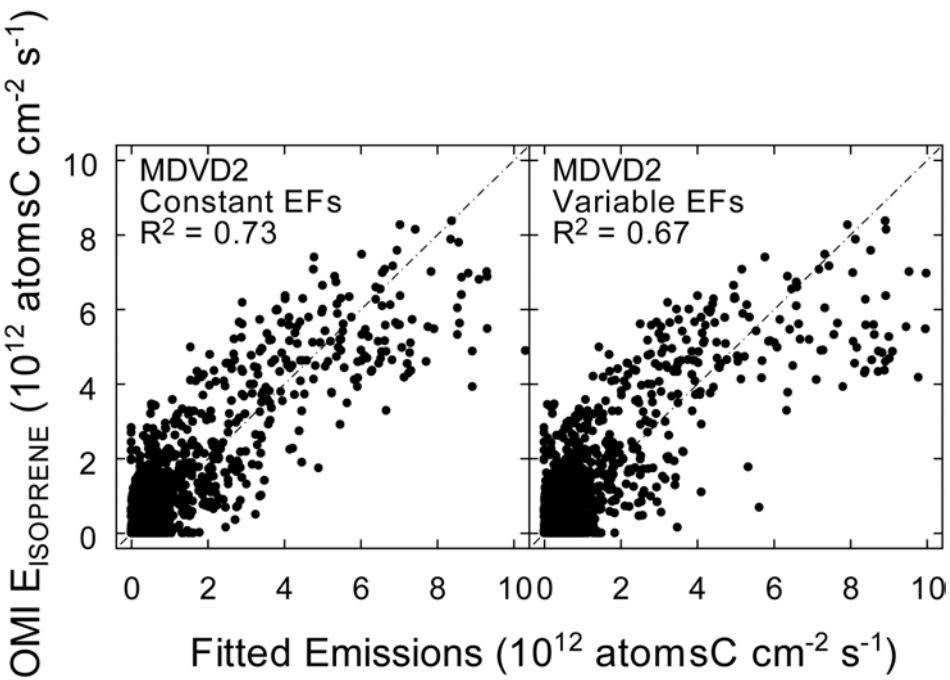
CLM Fineleaf Evergreens

CLM Crops



[%]

Constraints on Emission Factors



Regress OMI isoprene emissions against MDVD2 PFTs

Constant EFs

More consistent with OMI

Optimum broadleaf tree EF:

- 13 x 10^{12} atomsC/cm^2/s
- similar to MEGAN mean
- rejects MEGAN's use of 3-4x higher EFs in certain locations

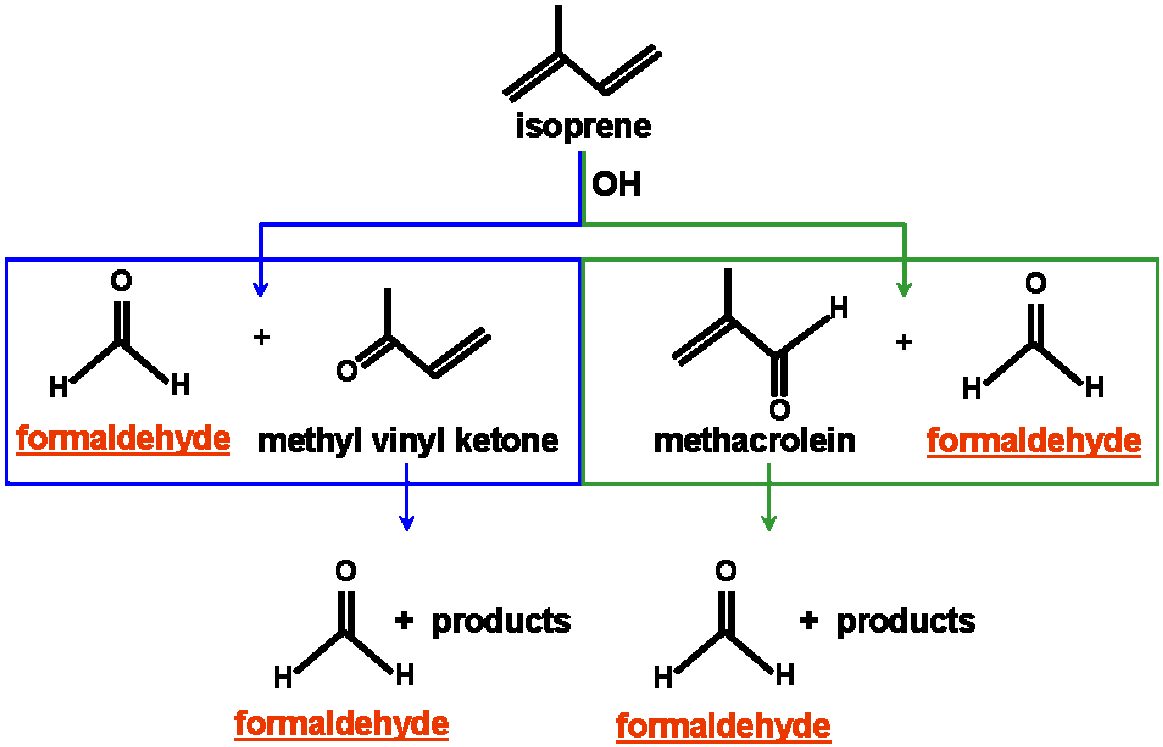
Possible explanation for OMI-MEGAN discrepancy:
Fast chemical loss within forest canopies?

Farmer and Cohen [2007] , Kuhn et al. [2007]

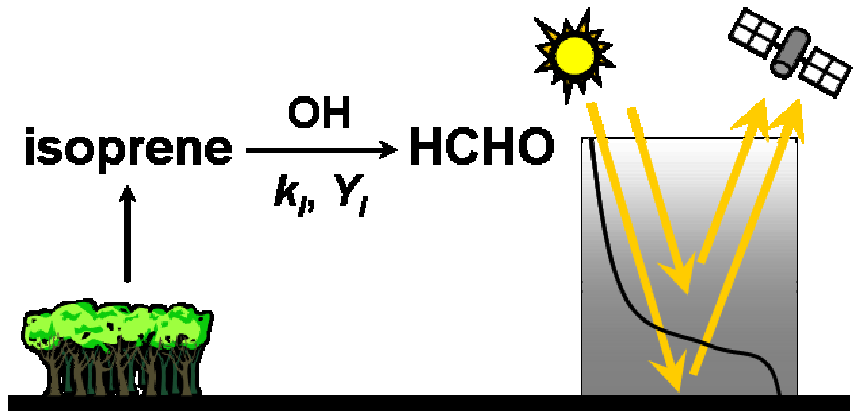
Extra Slides

Mapping Isoprene Emissions from Space

Formaldehyde (HCHO) is a major breakdown product in the oxidation of isoprene



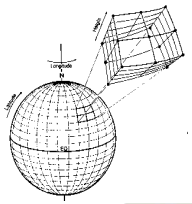
➔ Giving us an isoprene emission proxy that can be measured from space



Bottom-Up Biogenic VOC Emission Estimates

Can we derive top-down constraints from satellites to test the bottom-up inventories?

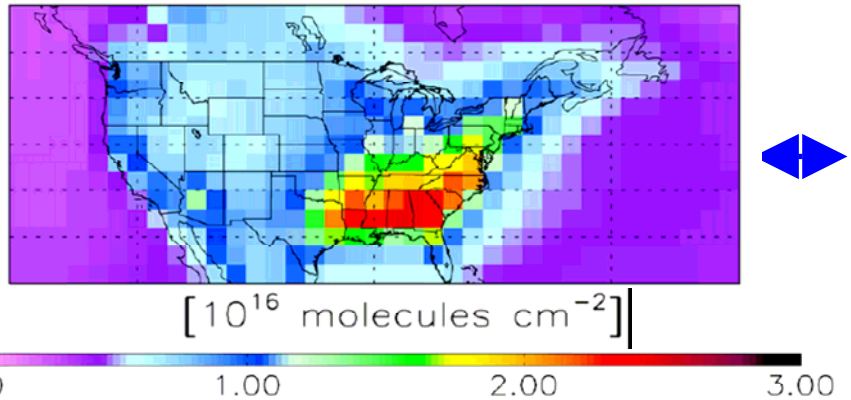
HCHO Column Distribution over North America



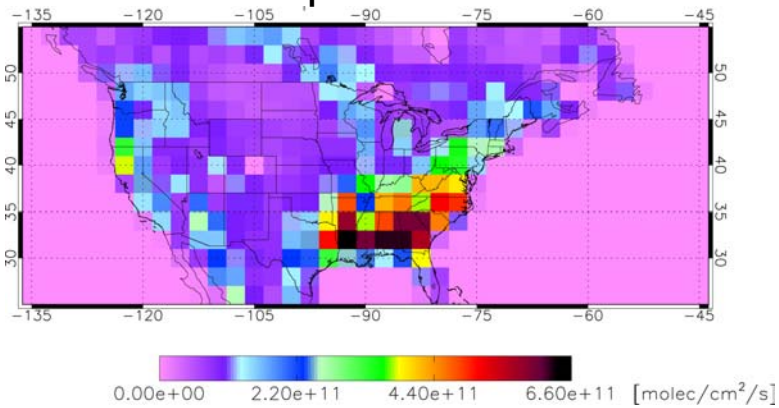
GEOS-Chem global 3D model of atmospheric chemistry

driven by assimilated meteorology

Modeled HCHO Columns



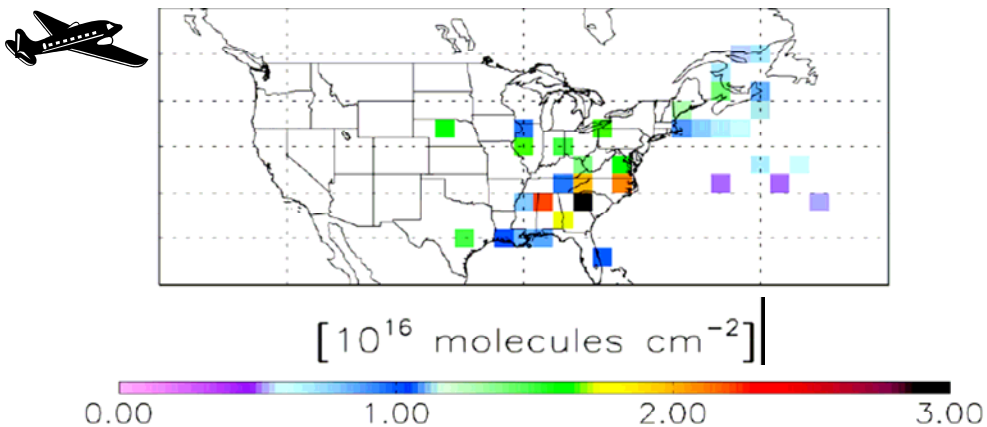
MEGAN Isoprene Emissions



INTEX-A aircraft experiment

summer 2004

Measured HCHO Columns



Millet et al., JGR (2006).

GEOS-Chem Global 3D Model of Atmospheric Chemistry

GEOS-4 assimilated meteorological data from the NASA Goddard Earth Observing System

winds, convective mass fluxes, mixing depths, temperature, precipitation, surface properties
6-hour temporal resolution (3-hour for surface variables and mixing depths)
1° × 1.25° horizontal resolution (degraded to 2x2.5 for input to GEOS-Chem)
55 vertical layers
advection every 15 minutes using a flux-form semi-Langrangian method (Lin and Rood, 1996)

Emissions

anthropogenic (EPA NEI99, BRAVO, EDGAR, EMEP, Streets)
biogenic (MEGAN, Jacob 2002 & 2005, Yienger and Levy 1995)
biomass burning (GFED2) & biofuel

Ozone-NOx-VOC chemistry coupled to aerosols

Dry deposition

standard resistance-in-series scheme (Wesely, 1989)

Wet deposition

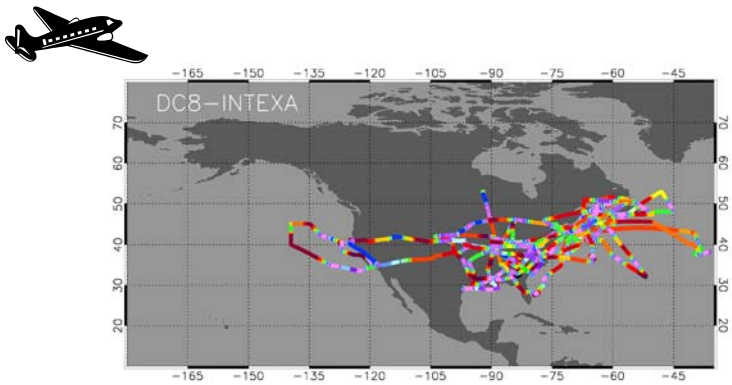
convective scavenging, rainout (in-cloud), washout (below-cloud) (Liu, 2001)

Aerosol chemistry and radiative effects

Testing HCHO Column Measurements From Space

Aircraft Measurements

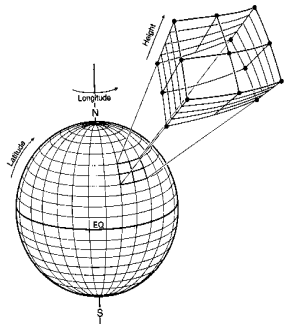
INTEX-A atmospheric chemistry experiment over North America (summer 2004)



Chemical transport modeling

GEOS-Chem global 3D model of atmospheric chemistry

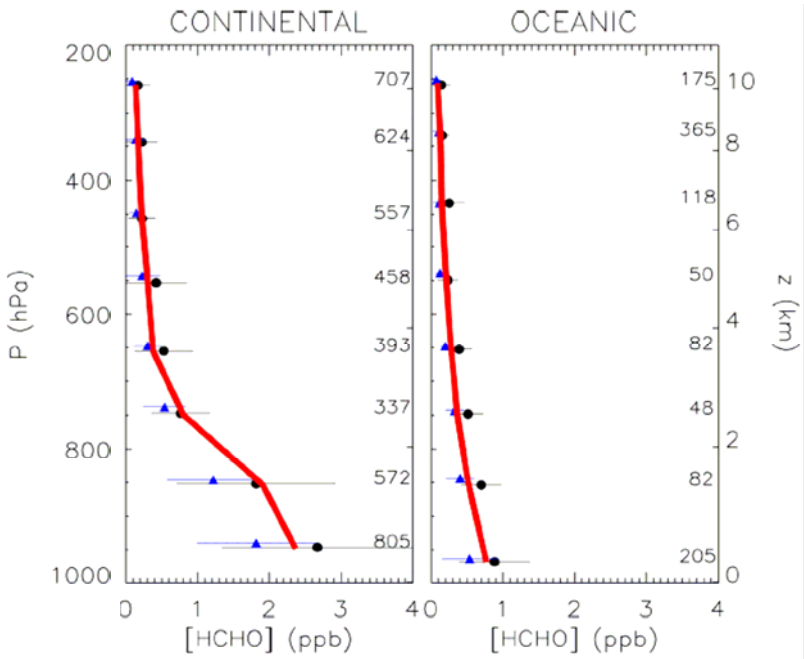
Driven by assimilated meteorology



Source of external information in HCHO retrieval

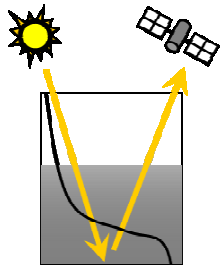
● ▲ Observed HCHO

— Simulated HCHO

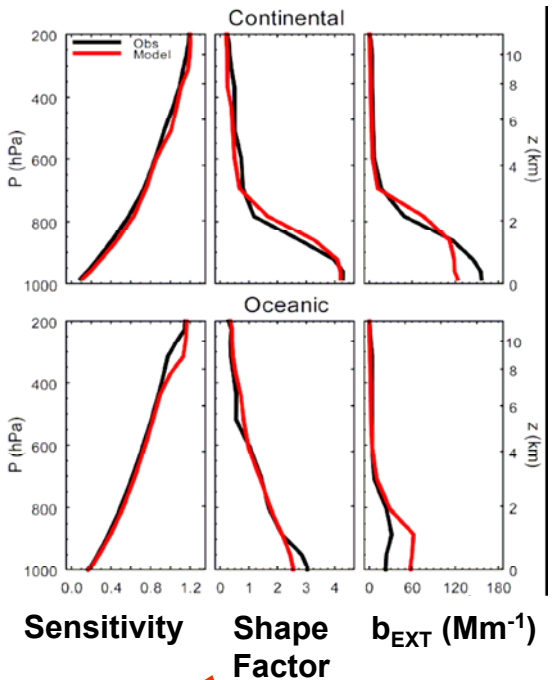


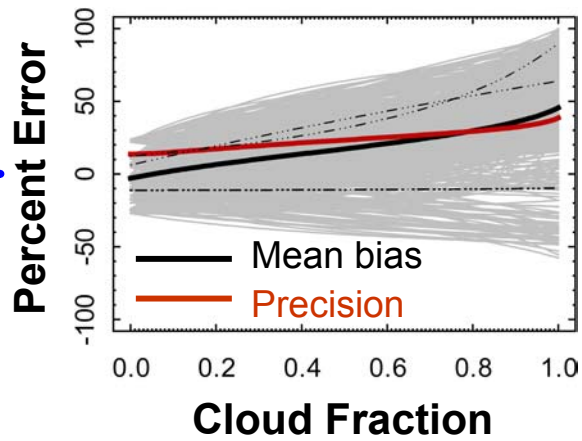
HCHO vertical distribution well simulated

Testing HCHO Column Measurements From Space



$$\frac{\Omega_{slant}}{\Omega_{vertical}} = f\,(\text{atmospheric scattering, HCHO vertical profile, surface albedo})$$

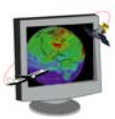




Clouds: primary source of error

1σ error in HCHO satellite measurements: 25–31%

Recommended cloud cutoff: 50%

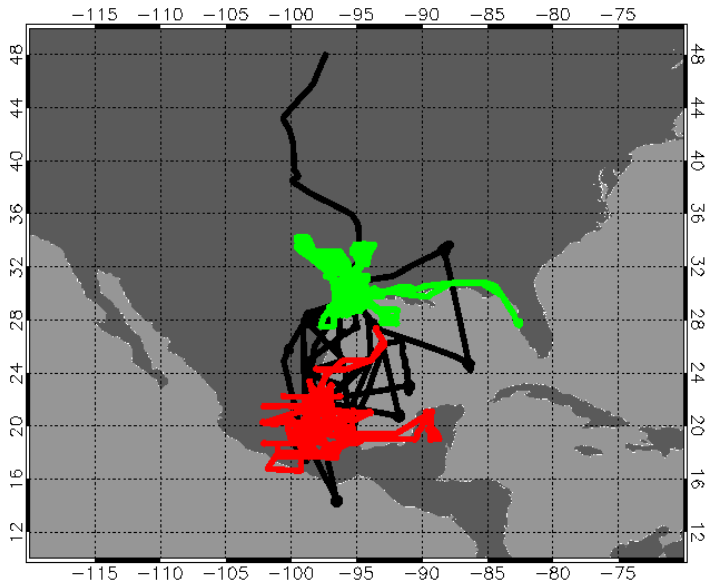


Millet et al., JGR (2006).

Testing HCHO Column Measurements From Space

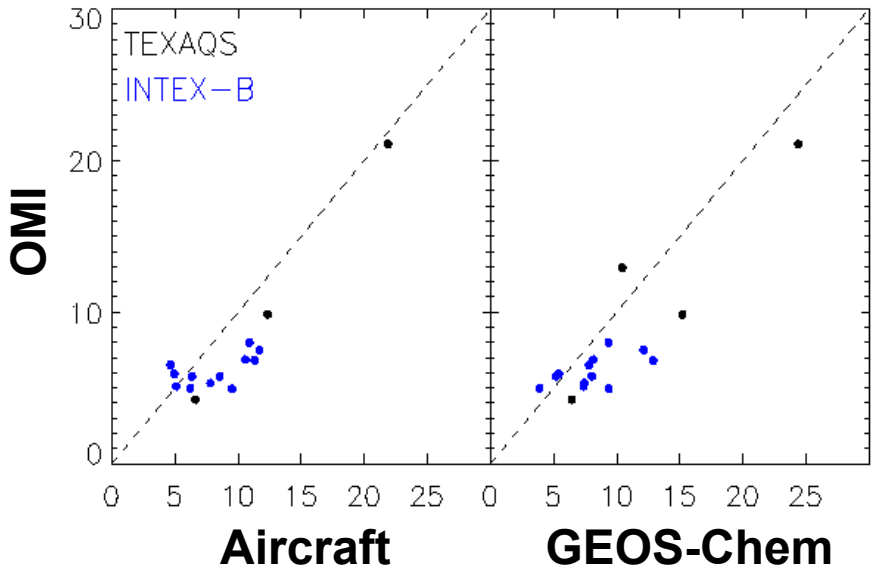
2006 Aircraft Campaigns

INTEX-B
MILAGRO
TEXAQS-2006



OMI vs. Aircraft Data & GEOS-Chem

HCHO Columns
[10^{15} molecules cm^{-2}]

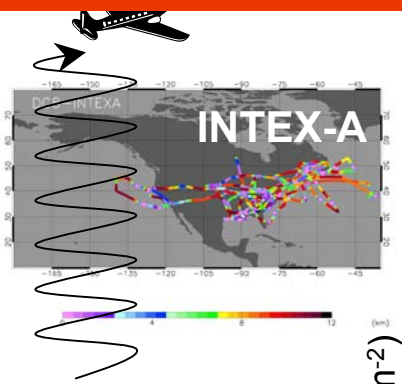


Aircraft measurements by A. Fried

Limited direct validation data shows consistency between aircraft measurements and OMI

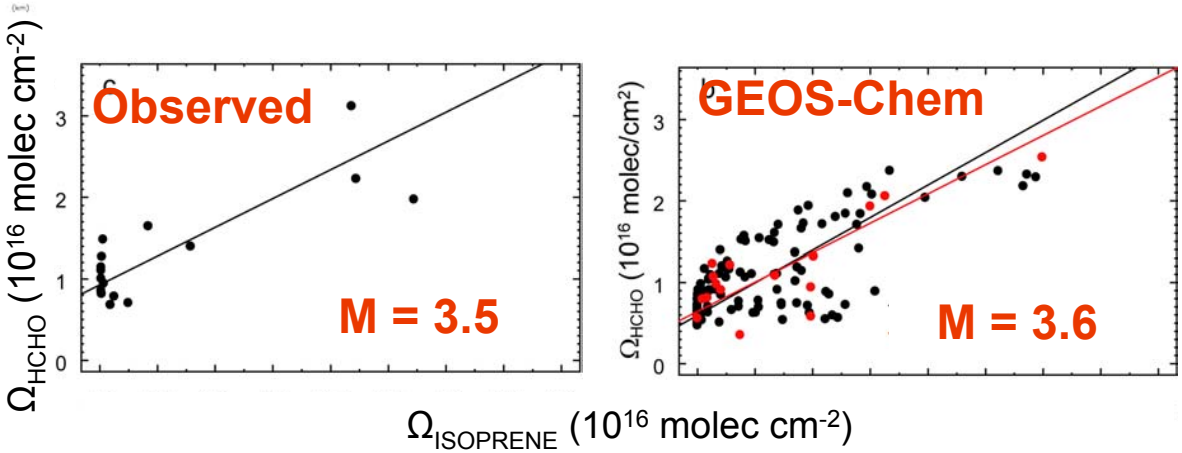
D. Millet

Relating HCHO Columns to Isoprene Emission



Testing the Modeled Ω_{HCHO}-$E_{isoprene}$ Slope

$$\Omega_{HCHO} = S \cdot E_{isoprene} + B$$



HCHO yield from isoprene

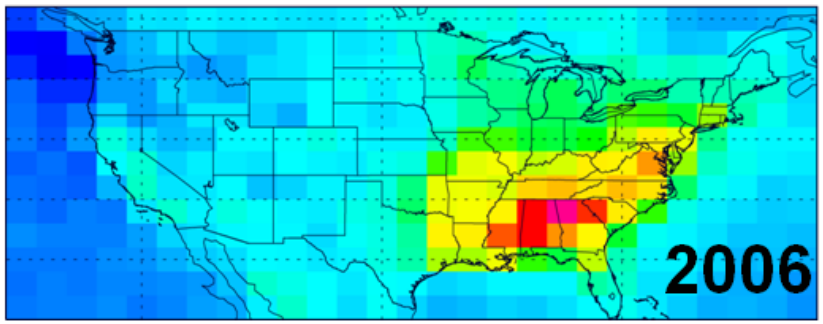
From aircraft profiles during INTEX-A:
HCHO yield from isoprene = 1.6 ± 0.5

Consistent with current chemical mechanisms

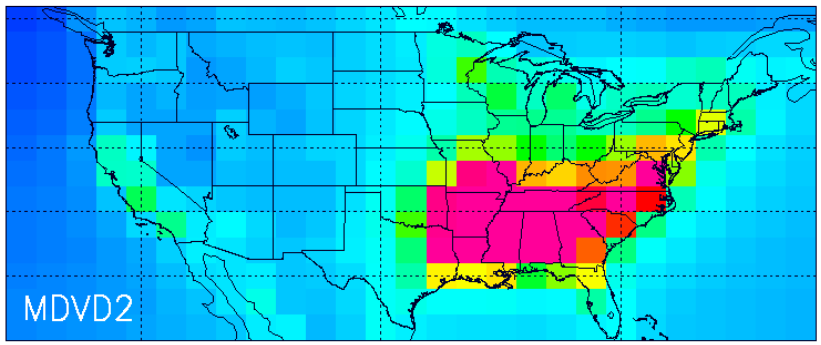
Millet et al., JGR (2006).

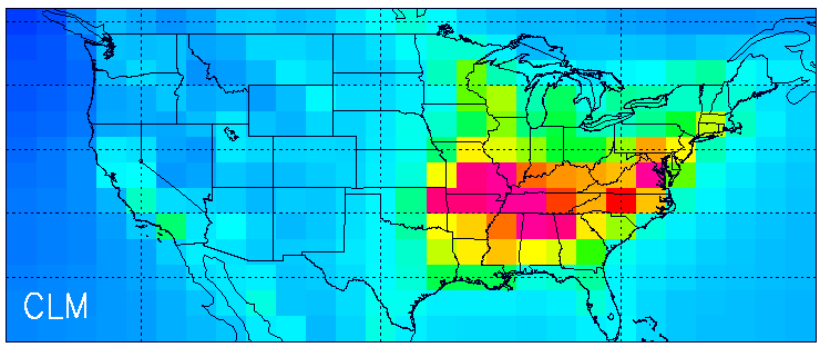
OMI vs. GEOS-Chem with MEGAN Emissions

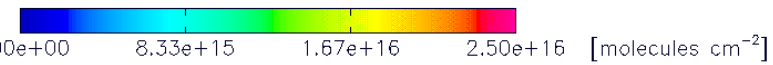
OMI

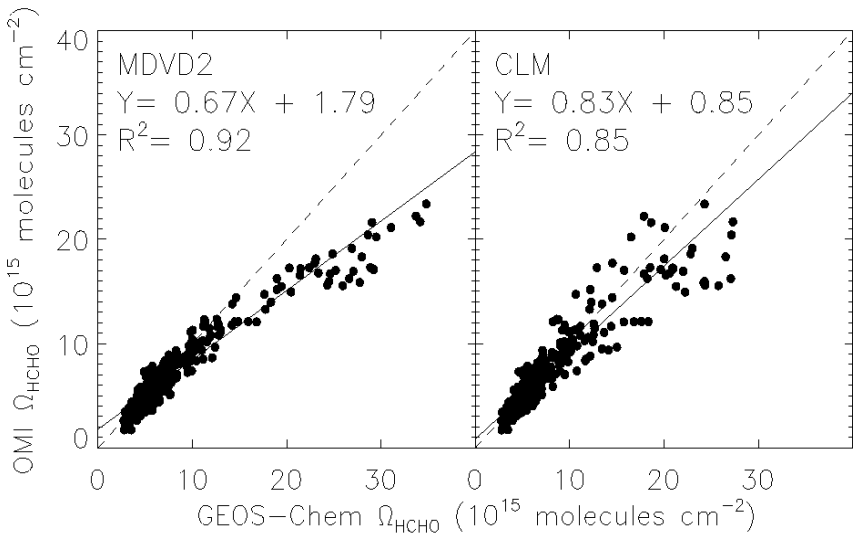


GEOS-Chem

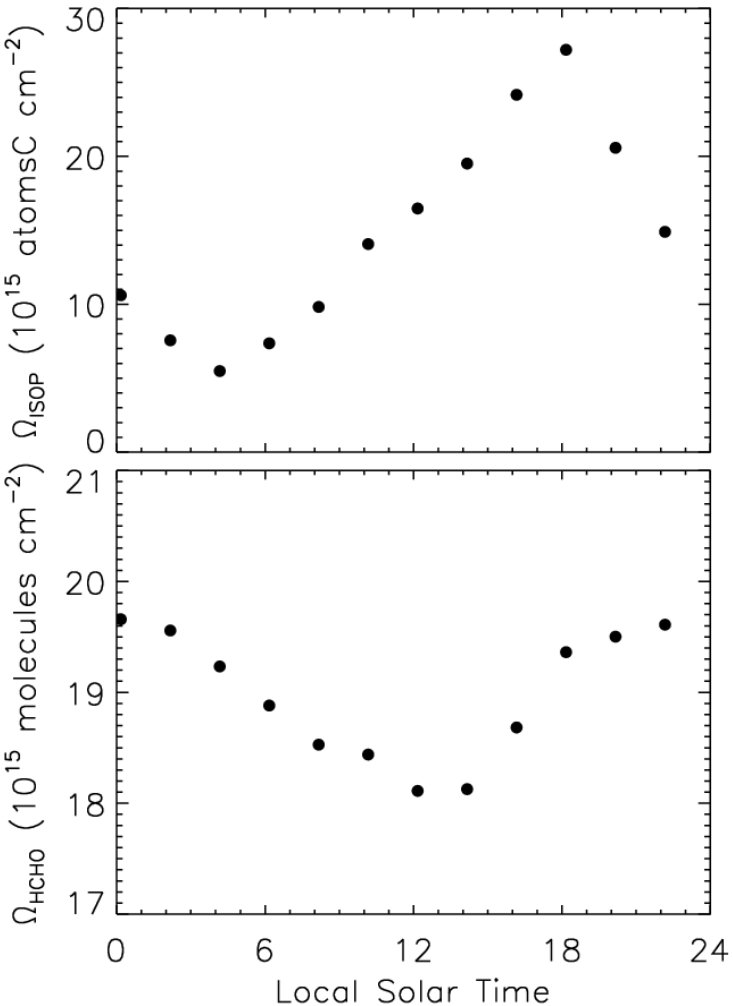






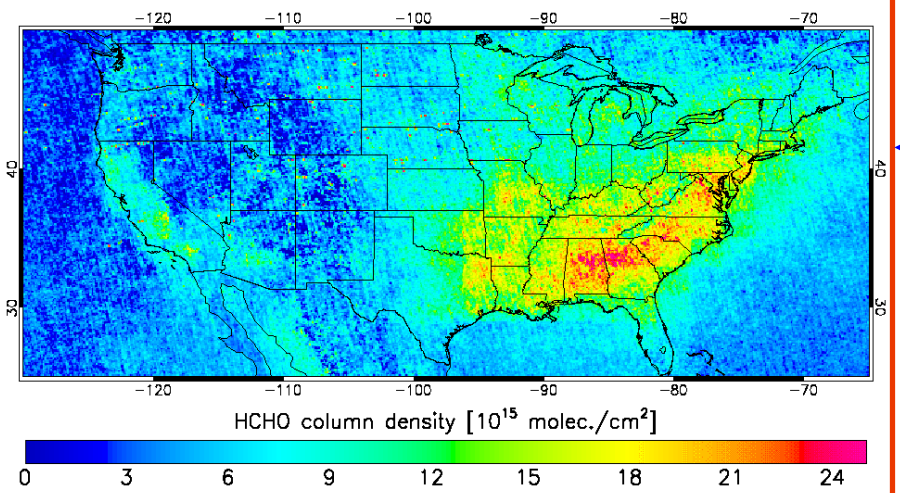


Diel Cycle in Isoprene and HCHO Columns over SE US



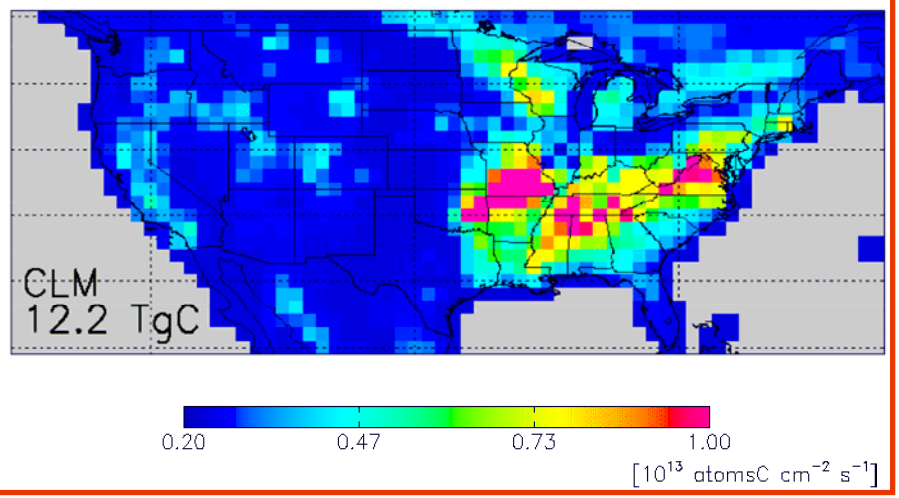
Defining Spatial Distribution of $E_{isoprene}$ Using OMI HCHO

HCHO columns from OMI satellite instrument (summer 2006)



?

Isoprene emissions from the MEGAN biogenic emission inventory (summer 2006)



test bottom-up inventories against top-down constraints from OMI

mismatch in hotspot locations

implications for OH, O_3, SOA production